INFLUENCE OF HOLES ON THE IN-PLANE TENSILE STRENGTH AND FATIGUE DURABILITY OF A NICALON^{TM}/SI-N-C CERAMIC MATRIX COMPOSITE

Sreeramesh Kalluri
Ohio Aerospace Institute
NASA Glenn Research Center
21000 Brookpark Road M/S 49-7
Brook Park, Ohio 44135

Michael J. Verrilli
NASA Glenn Research Center
21000 Brookpark Road M/S 106-5
Brook Park, Ohio 44135

ABSTRACT

Effects of different sizes of holes as well as different percentages of open areas on the in-plane tensile strength and fatigue durability of the SiC/Si-N-C composite were investigated in this study. Test specimens with no holes, four different diameters of holes (1.0 to 3.2 mm), and four different open areas (20 to 35%) were machined. All mechanical testing was performed in air at a temperature of 910 °C. Fatigue tests were conducted with a load ratio, $R = 0.05$, and a frequency of 0.33 Hz. In general, both the in-plane tensile strength of the composite and its fatigue durability decreased with an increase in the size of the hole and percentage of the open area. Reductions in the in-plane tensile strength and cyclic fatigue life of the composite were described by empirical equations with the diameter of the hole and the percent open area as the independent variables. The validity of these two empirical equations was verified with additional tensile and fatigue test data generated on the composite specimens.

INTRODUCTION

A woven, Nicalon^{TM} fiber-reinforced, Si-N-C matrix composite (SiC/Si-N-C) was considered as acoustic liner's tile material in the exhaust nozzle of the High Speed Civil Transport gas turbine engine. Design of these tiles included hexagonal arrays of small holes in the composite material [1]. In the gas turbine engine these acoustic tiles would be exposed to environments containing air, humidity, and salt-fog. The fatigue behavior of Nicalon^{TM} /Si-N-C composite with holes under these types of environmental conditions was previously reported [2].

In this study, the in-plane tensile strength and fatigue behavior of Nicalon^{TM} /Si-N-C composite with no holes and with different patterns of holes were characterized at 910°C in air. Baseline properties for the composite were established with data generated on solid (no holes) specimens. Effects of the diameter of the hole and percent open area (POA) were quantified and verified with data obtained from the specimens with holes.

MATERIAL AND SPECIMENS

The quasi-isotropic ([0/±45/90]s lay up) SiC/Si-N-C composite material was manufactured by the Dow Corning Corporation with the polymer impregnation and pyrolysis (PIP) method [3]. Nicalon^{TM} fiber mats woven in an eight harness satin weave configuration were assembled to the required lay up. Additional details on the manufacturing process of the composite are available in Ref. [2]. Test specimens with no holes and test specimen blanks were machined from the nominally 2.8 mm thick SiC/Si-N-C composite plates by diamond grinding. Ultrasonic machining was used to drill holes with nominal diameters of 1.0, 1.8, 2.5, and 3.2 mm in the test specimen blanks. After drilling edges of the holes were sealed by additional PIP cycles. For test specimens with holes, widths were determined by the hole-pattern and POA in the test section. Test specimens with 0 (no holes), 20, 25, 30, and 35 POA (all with nominally 1.8 mm diameter holes) are shown in Fig. 1.

Table I. Tensile and Fatigue Test Matrix for the SiC/Si-N-C composite at 910°C

Hole Dia. \ POA [%]	0	20	25	30	35
0 mm	2, 4	-	-	-	-
1.0 mm	-	2, 2	-	-	2, 2
1.8 mm	-	2, 2	2, 2	2, 2	2, 2
2.5 mm	-	-	-	-	2, 2
3.2 mm	-	-	-	-	2, 2

EXPERIMENTAL DETAILS

The tensile and fatigue test matrix for the SiC/Si-N-C composite is shown in Table I. For a given set of hole diameter and POA, the first and second entries in the table indicate the number of specimens tested under monotonic tensile and fatigue conditions, respectively. All tensile (stroke-control) and fatigue (load-control) tests were conducted at 910°C in air. Test specimens were heated in a susceptor and during the test, temperature was controlled and monitored with two R-type thermocouples located inside the susceptor. All the fatigue tests were conducted at a frequency of 0.33 Hz with a maximum stress of 131 MPa and $R = \sigma_{min}/\sigma_{max} = 0.05$. In the tensile and fatigue tests on specimens with holes, strength and stress values, respectively, were computed with the net cross sectional areas of the specimens. Failure was defined in the fatigue tests as separation of the test specimen into two pieces. In all the specimens containing holes, final fatigue crack occurred across the test section by following a path through the pattern of holes.

RESULTS

Tensile Behavior

Tensile properties from the 0 (no holes) and 25 and 35 POA (1.8 mm holes) test specimens were previously reported in Ref. 2. The average values of tensile properties reported in Ref. 2 for the 0 POA (no holes) test specimens were as follows: Elastic modulus, 104 GPa; in-plane tensile strength, 222 MPa; and proportional limit strength (0.05% offset), 130 MPa. The average values of the net section tensile strengths (NSTSs) reported in Ref. 2 for the 25 and 35 POA test specimens were 201 and 163 MPa, respectively. Average net section tensile strengths obtained in the present study from the 20 and 30 POA (1.8 mm holes) test specimens were 210 and 173 MPa, respectively. A comparison of the average NSTSs for the 0 to 35 POA test specimens is shown in Fig. 2. Errors bars, if existing, indicate the extent of scatter in the data. For 1.8 mm holes, the NSTS decreased more or less in a linear fashion as POA increased due to the presence of the holes. For 35 POA, the average NSTSs obtained from specimens with 1.0, 1.8, 2.5, and 3.2 mm were 173, 163, 159, and 159, respectively. The influence of hole size on the average NSTS is indicated in Fig. 3. At a given POA, the size of hole appears to influence the NSTS of the composite only slightly.

Fatigue Behavior

For test specimens with 1.8 mm holes, geometric mean cyclic lives are shown in Fig. 4 for different POA values. Fatigue data from the 0 POA (no holes) and 25 & 35 POA (1.8 mm holes) test specimens included in Fig. 4 were previously reported in Ref. 2. The geometric mean fatigue life decreased as the POA increased for the composite (Fig. 4). As expected, the scatter exhibited in the fatigue data was more significant than that observed in the tensile tests. The effect of hole size on the geometric mean fatigue life of the composite is illustrated in Fig. 5. Even though, the geometric mean fatigue life of the composite at 35 POA was lower than that at 0 POA, fatigue life at 35 POA decreased as the hole size increased up to 2.5 mm and then exhibited a slight increase at a hole size of 3.2 mm.

DISCUSSION

In order to quantify the effects of both the hole size and POA on the tensile behavior and fatigue durability of the composite, linear relationships with the hole diameter, d (mm) and POA (%) as the independent variables and NSTS (MPa) and logarithm of fatigue life as the dependent variables, respectively, were calculated (Eqs. 1 and 2). These linear relationships for the NSTS and fatigue life of the composite are shown in Figs. 6 and 7, respectively. In these figures, the planes (appearing as meshes) denote the linear relationships (Eqs. 1 and 2) and the experimental data are shown as symbols.

$$\text{NSTS} = 232 - 1.49\text{d} - 1.75\text{POA} \qquad (1)$$

$$\text{Log}_{10}(\text{N}_f) = 4.674 - 0.1195\text{d} - 0.03824\text{POA} \qquad (2)$$

NSTS and fatigue life data obtained from the 20 POA specimens with 1.0 mm diameter holes (Table I) were used to verify the predictive capabilities of Eqs. 1 and 2. The experimentally observed values were 189 and 197 MPa and 1 261 and 2 161 cycles, respectively, for the NSTS and fatigue life. Corresponding values predicted by Eqs. 1 and 2 were 196 MPa and 6 161 cycles, respectively. For 20 POA with 1.0 mm diameter holes, the prediction of NSTS with Eq. 1 was within the range of the experimentally observed values, whereas the fatigue life predicted by Eq. 2 was higher by about factors of 3 to 5. This discrepancy between the tensile and fatigue predictions was not surprising because more scatter was observed in fatigue lives than the tensile strength values of the composite (Figs. 2 to 5).

SUMMARY

In-plane tensile strength and fatigue behavior of a woven, Nicalon™ /Si-N-C composite containing no holes and arrays of holes with different sizes of holes and open areas were investigated at 910° in air. As anticipated, both the net section tensile strength and fatigue durability of the composite decreased due to the presence of the holes. Effects of the hole size as well as the open area on the net section tensile strength and fatigue durability were quantified with simple equations for the conditions investigated in this study. These relationships were verified with additional tensile and fatigue data generated on the composite material.

ACKNOWLEDGEMENTS

Financial Support for this work was obtained from the Ultra Efficient Engine Technology program at NASA Glenn Research Center, Brook Park, Ohio under cooperative agreement NCC-3-618. Authors are grateful to Mr. John Arnold, Mr. William L. Brown, and Mr. John D. Zima for conducting the tensile and fatigue tests.

REFERENCES

[1] A. Pacia, R. Crumbacher, K. R. Wentz, and M. P. Camden, "Combined Thermal/Acoustics Testing of Ceramic Matrix Composite Nozzle Exhaust Components," Proceedings of the 69th Shock and Vibration Symposium held in St. Paul, Minnesota, October 12-16, 1998.

[2] S. Kalluri, M. J. Verrilli, and G. C. Ojard, "Effect of Environment on Fatigue Behavior of a Nicalon™ /Si-N-C Ceramic Matrix Composite," 26th

Annual Conference on Composites, Advanced Ceramics, Materials, and Structures: A, Ceramic Engineering and Science Proceedings, Vol. 23, Issue 3, H.-T. Lin and M. Singh, Eds., pp. 589-598, 2002.

[3] R. Jones, A. Szweda, and D. Petrak, "Polymer Derived Ceramic Matrix Composites," *Composites, Part A: Applied Science and Manufacturing*, 30, pp. 569-575, 1999.

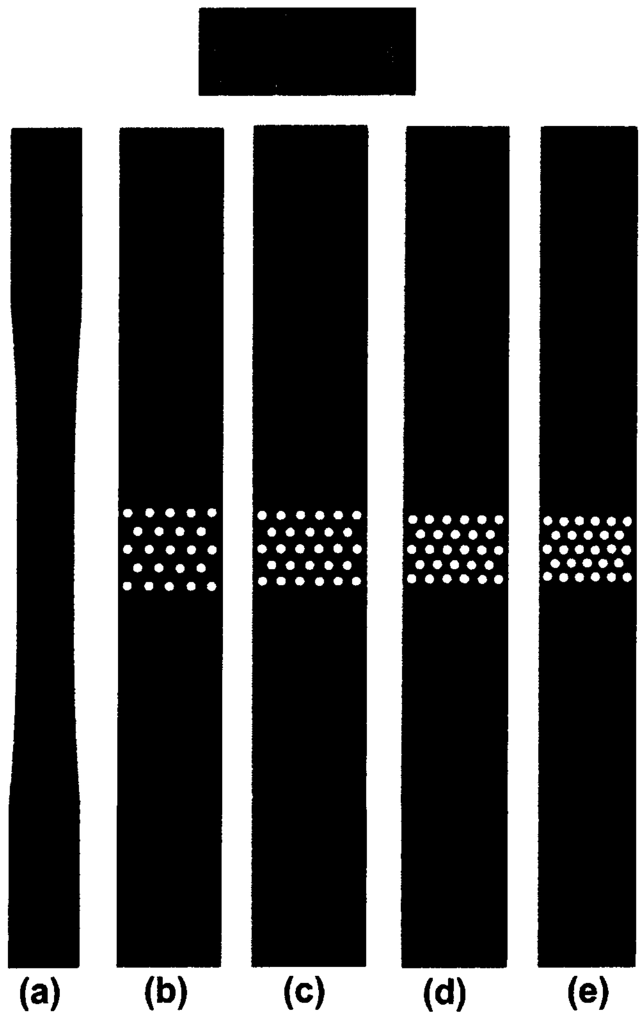

Figure 1: SiC/Si-N-C composite test specimens: (a) 0 (no holes), (b) 20, (c) 25, (d) 30 and (e) 35 POA (nominally 1.8 mm diameter holes).

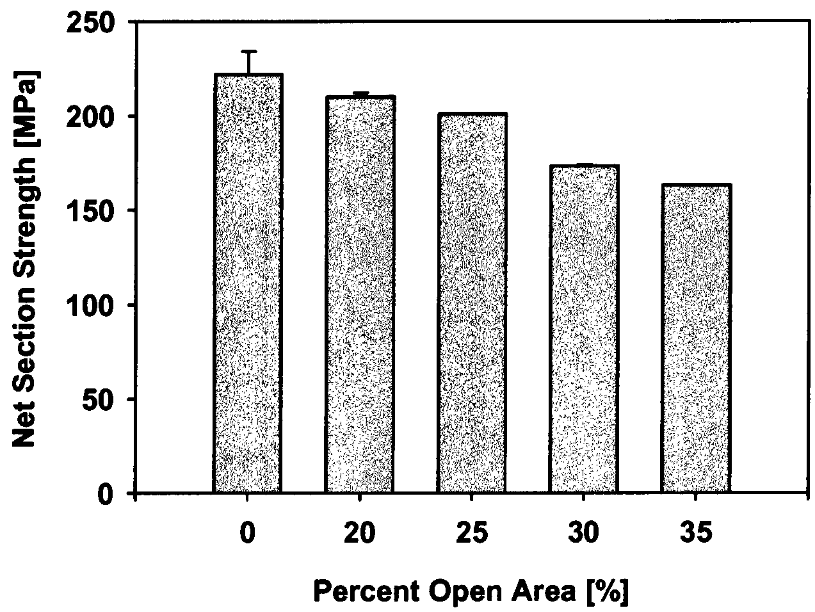

Figure 2: Comparison of average net section tensile strengths for 0, 20, 25, 30, and 35 POA specimens with 1.8 mm diameter holes.

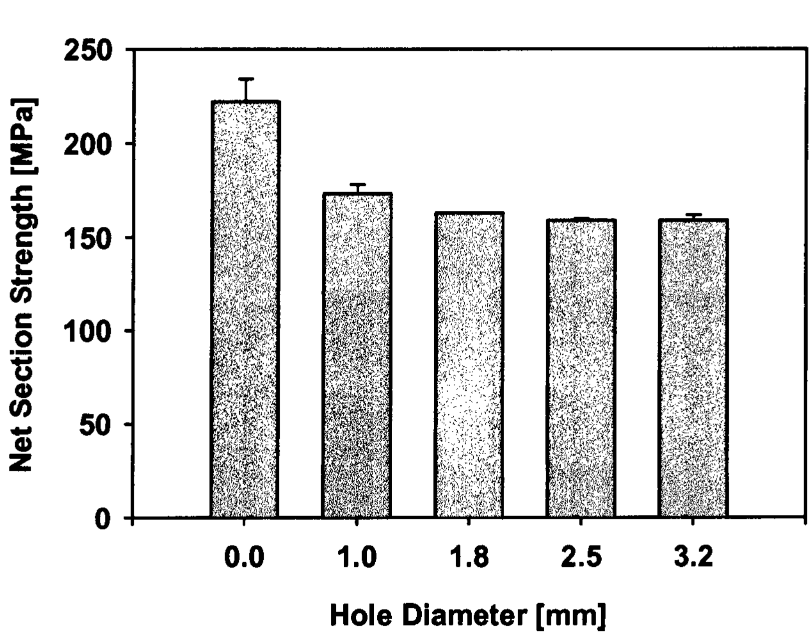

Figure 3: Comparison of average net section tensile strengths for 35 POA specimens containing holes of different diameters.

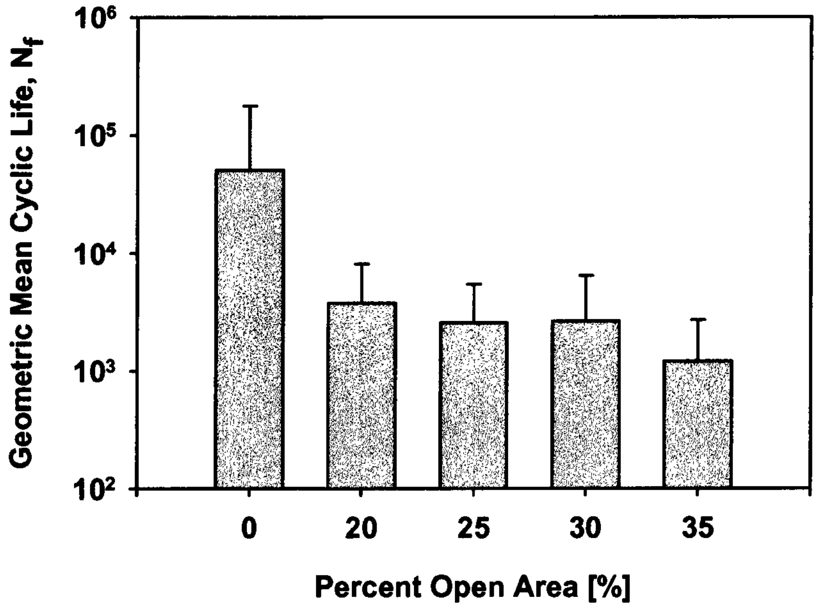

Figure 4: Comparison of geometric mean fatigue lives for 0, 20, 25, 30, and 35 POA specimens with 1.8 mm diameter holes.

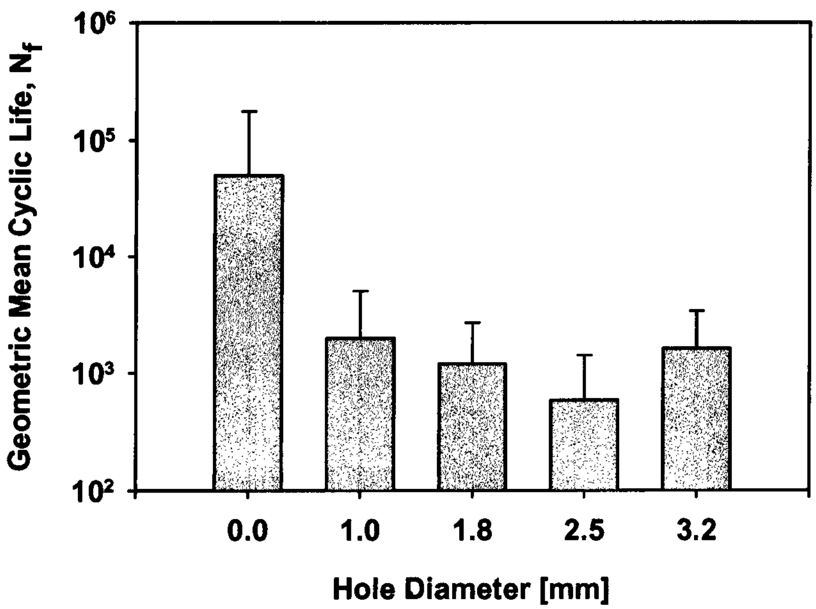

Figure 5: Comparison of geometric mean fatigue lives for 35 POA specimens containing holes of different diameters.

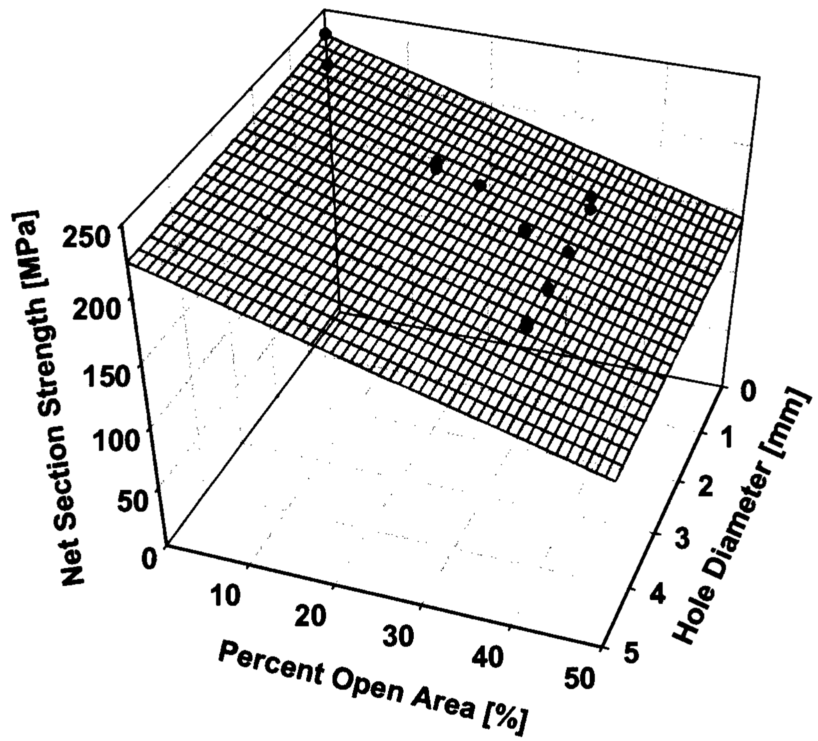

Figure 6: Variation of net section tensile strength with hole diameter and POA.

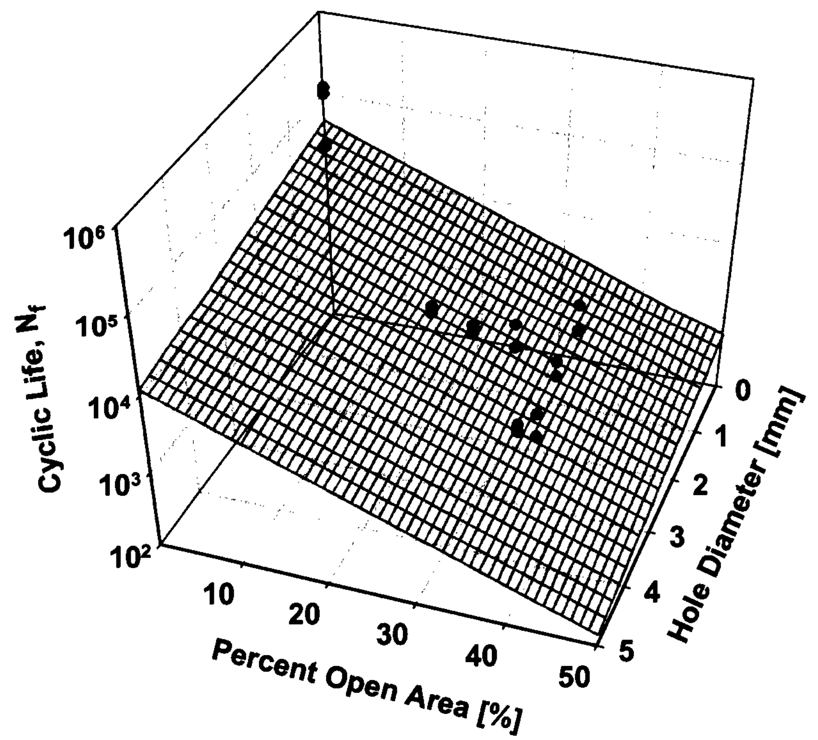

Figure 7: Variation of fatigue life with the hole diameter and POA.